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The influence of malt quality and malting technology on the flavour stability of beer

Brewing trials of different produced malts were carried out to investigate the influence of malt quality and malting technology on flavour stability of beer. All interpretations of the results of these malting and brewing trials are done in consideration of malting technology and in matters of flavour stability. An evaluation of the barley variety is not possible due to the number of trials for each variety and was not intention of this work. The trials comprised nine commercial and one pilot plant (200 kg) malts of the varieties Annabell, Auriga, Braemar (grown in Baden-Wurttemberg), Barke (grown in Franconia) and Scarlett (grown and malted in France). The malting conditions of the German malts were similar, i. e. seven vegetation days (steeping and germination), the kilning procedures varied with respect to the cycle length and the final temperatures between 78 and 90 °C. The beers were processed in a pilot plant (scale: 60 l cast out wort).
The resulting data point out, that lipids and their degradation products show a negative impact on beer flavour and flavour stability, but they are mostly not dominant in the flavour profile of fresh and forced aged beer. They can be used as analytical indicators, but the Strecker aldehydes exercise the main influence on the formation of stale flavours. The thiobarbituric acid index (TBI) in malt, unboiled wort and fresh beer was found to correlate highly with the sum of Strecker aldehydes and the tasting results of the aged beer.

Descriptors: malt quality, malting technology, aroma compounds, Strecker aldehydes, TBI, beer quality, flavour stability

1 Introduction

The strong influence of malt on beer quality is broadly accepted [64-68]. To understand the influence of malt on the flavour stability it is necessary to gain an insight into the complex processes of beer ageing.

Flavour stability can not easily be related to a single process in brewing technology. The three most important influencing factors are the

1. formation of ageing components (Strecker aldehydes, fatty-acid degradation products),
2. protective attributes of antioxidative substances (SO_2, phenols, etc.) and
3. masking effects of flavours compounds (linalool, esters, etc.).

In general it is not possible to relate the contribution of individual substances to the ageing flavour, therefore all components are considered as ageing relevant which increase parallel to the detectable sensory ageing flavour impression [2, 17, 18, 30, 35, 38, 39, 45, 47, 54, 55, 57, 60-62]. The formation of ageing compounds is mainly caused by oxidation reactions. Very low concentrations of oxygen as they are inevitable even by an optimum bottling are already enough to start oxidation reactions. The antioxidative beer ingredients can delay the formation of the ageing aroma and thus counteract the oxidation reactions [3, 4, 6, 7, 23, 25, 32, 36, 50, 56]. Besides the formation of stale flavour components and antioxidant effects the loss of positive flavour and aroma compounds during the storage of bottled beer favours the perception of stale flavour [41, 48, 56]. These various processes cause continuous changes of the sensory characteristics of beer during storage.

Aspects of flavour stability can be manipulated throughout the brewing process. For example it is possible to influence the phenol content (antioxidative components) in the brewhouse [4, 28, 36, 56], the content and the evaporation of Strecker aldehydes (ageing components) and formation/addition of various flavour compounds, which are able to cause masking effects [4, 5, 10, 21, 24, 29]. During fermentation SO_2 (antioxidative component) [4, 9, 19, 20, 42, 63] and esters (flavour/masking components) [59] are formed, whilst carbonyls (ageing components) are reduced [4, 29].

Since there are different processes involved in beer ageing various methods of analysis have been proposed to measure flavour stability. Especially the measurement of ageing components in forced aged beer [12, 21, 30, 35, 37-40] and the measurement of the antioxidative potential of beer [4, 14-16, 22, 37, 49, 51-53] are known to be able to estimate flavour stability of beer. Investigation of the beers of one brewery showed that the ageing indicators correlate well with the sensory evaluation of beer [11, 29, 38-40]. It should be noted that investigations into flavour stability always have to consider all the influencing factors even if only one aspect is being investigated. A change in one technological parameter may alter the desired factors influencing flavour stability but may simultaneously change any of the others influencing factors unwillingly as well. A misinterpretation of the trial would be the result.

From this general overview about flavour stability it is evident that already the malt used for beer-production influences flavour stability. For example, the amount and the composition of reducing substances coming from the malt influence flavour stability. Also nitrogenous material and reducing sugars can act starting substances for Maillard reaction and Strecker degradation.

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Tables and Figures see Appendix

To influence the barley breeding and the malting procedures in a way to improve flavour stability will be a difficult task since the malt quality has to fit in various specifications in order to avoid problems in the further brewing process. For example the malts also have to fulfil the specifications for proteolysis, homogeneous cell wall modification, DMS, colour and TBI and some of these specifications are conflictive. Aim of this research project, which was done in cooperation with Suntory Limited, Tokyo, Japan was the comparison of different actual German barley varieties and the investigation of their influence on the quality and the flavour stability of beer under the same brewing conditions. Furthermore different kilning systems (as for drying and kilning cycles) were taken into account.

2 Material and methods

The analysis of malt, wort and beer were done according to MEBAK standards [34, 43, 44]. ESR analysis (Lag-Time) was done using the method of Uchida et al. [53]. The analysis of volatile aroma compound was developed by the Lehrstuhl für Technologie der Brauerei I, Freising-Weihenstephan [21, 29, 33]. Sensory evaluation of fresh and forced beers were done according to the DLG scheme (score from 5 (best) to 1 (worst)) [34] and stale tasting according to Eichhorn (score from 1 (not aged) to 4 (extremely aged) in half scores). The acceptance describes the subjective impression of ageing by the panellist (100 % = not aged) [11, 29, 35]. The (E)-2-nonenal potential in fresh beer was analysed by Suntory Limited, Japan [8, 58]. LOX activity in malt was measured by the Lehrstuhl für Technologie der Brauerei I, Freising-Weihenstephan [46].

Malt samples were produced from the following varieties [1]:

The German barley acreage was 730000 ha (yield 4.83 t/ha) in year 2003. The amount of brewing barley was 1.9 million tons.

- Barke (standard variety in barley trials, 15.9 % of the German barley vegetation area, very strong in Bavaria)
- Annabell (3.7 % of the German barley vegetation area, good brewing quality)
- Auriga (increasing importance, 8.1 % of the German barley vegetation area, widespread in Germany)
- Braemar (increasing importance, 7.2 % of the German barley vegetation area)
- Scarlett (commercial malt, planted and malted in France)

Maltings

Steeping and germination

All malts were produced in a similar way with a vegetation time of 7 days (steeping and germination time).

Kilning

System 1: To reduce energy consumption, some kilning systems were developed using the exhaust air after the breakthrough to contribute to the drying (withering) step of a following kiln. In one of these compound kilning systems, 40 % of the germinated green malt were dried and kilned in a 20 hour cycle, whereas the other 60 % were dried and kilned in a 36 hour cycle. The malt samples produced with this system (see Table 1) named Auriga 2 and 3 were kilned off at 90 °C to meet the specification of DMS-P.

System 2: Kilning of the samples Annabell, Auriga 1, Barke 1, Barke 4 and Braemar was done with a single floor kiln in a 20 hour cycle.

System 3: Barke 2 was malted within seven vegetation days, following a 36 hours cycle for drying and kilning. The exhaust air after breakthrough was used to contribute to drying (withering). Another trial using this system was Barke 3. Hence, the germination was run under 100 % return air. This means that CO_2 was enriched in the process air to suppress the action of LOX.

Wort production

The wort production was carried out in a 60 litre (scale: 60 l cast-out wort) scale pilot brewing plant. Malt was milled with a two-roll mill using a 0.8 mm gap. The temperature profile of the infusion mashing is shown in Figure 1. The malt/liquor ratio was 1:4. The wort was boiled for 70 minutes at atmospheric pressure. Hopping was done at the beginning of wort boiling with Hallertauer Taurus (16 % α) in order to reach 22 BU in beer. The whirlpool rest lasted 20 minutes.

Beer production

Fermentation and storage time is displayed in Figure 2. After three weeks of cold storage the beers were filtered with a sheet filter. Bottling was done with a single-organ long-tube filler with CO_2-flushing and pre-evacuation.

3 Results and discussion

Malt analysis

Short evaluation of the individual malts

The resulting malts Annabell, Auriga and Braemar were of very good brewing quality. Only Annabell was not in brewing specifications because of a high Kolbach-Index (KI) and the resulting higher colours. Between the different malting technologies (variety Auriga) an obvious influence of drying and kilning procedures was detected. The longer cycle fostered a better homogeneity, the higher β-glucan level was atypical, but still fairly low.

The Barke malts were as well of very good brewing quality. The proteolytic modification in the kilning system 3 was slightly lower, but this could be desirable with regard to good flavour stability. The KI of variety Barke was relatively low and therefore tended to lower colours. Although two different malting-systems where used, there might be an influence of the longer procedure during drying and kilning. Scarlett fitted very nicely into the specifications, but may require a somewhat more intensive mashing procedure to avoid filtration difficulties because of a relatively high viscosity and low friability.

The complete data of malt analysis are given in Table 2.

Annabell: extract quite low (depends on area and climate); very good cytolytic modification according to all criteria: friabilimeter, viscosity, β-glucan in the 65 °C-wort, modification and homogeneity; proteolytic modification a bit too high for this variety, high Congress wort-colour (CWC) and boiled wort-colour (BWC) as a result of this. Due to the high colour, TBI was also high. The final attenuation was relatively low, the lowest of all the malts.

Auriga 1: "normal" specifications, extract and cytolysis good, but

Auriga 2: extract like Auriga 1; slightly poorer cytolysis expressed in β-glucan, friabilimeter, higher viscosity, but very good modification and homogeneity. Proteolysis almost equal to Auriga 1; CWC and BWC slightly higher; TBI high (!); DMS-P normal.

slightly lower than Auriga 2 and 3; modification and homogeneity were very high in combination with a slightly high, but well balanced proteolysis; relatively high DMS-P; TBI relatively low.

Auriga 3: extract like Auriga 1 and 2; slightly higher viscosity, but good friability; modification and homogeneity very good; β-glucan higher than Auriga 2; proteolysis equal to Auriga 2; DMS-P normal; colours a bit lower than longer cycle malt; TBI medium.

Braemar: same protein content like malt samples Barke, Scarlett and Annabell; very high and homogeneous cytolysis; normal, slightly high proteolysis which is well balanced; colours normal, BWC slightly elevated; DMS-P very high and TBI low due to low kilning temperature; very high final attenuation.

Barke 1: very high extract; very good cytolysis, according to all the criteria. Proteolysis too high (KI 44.5 %); DMS-P normal; colours low; TBI low.

Barke 2: extract very high; cytolysis slightly lower than Barke 1; good modification and homogeneity; proteolysis (KI) normal; DMS-P more favourable than Barke 1; colours similar; TBI low.

Barke 3: relative high viscosity, but a confined proteolysis; DMS-P and TBI low.

Barke 4: very high extract; very good cytolysis; confined proteolysis; bright colour; DMS-P low; TBI low.

Scarlett (France)**:** very high extract; fairly high viscosity, also of 65 °C-wort; normal β-glucan; friabilimeter lower; modification high; homogeneity much lower than in the other malts (this is in certain years a problem of Scarlett). Proteolysis moderate; DMS-P low; TBI high like Annabell and Auriga 2.

Evaluation of worts and beers

The individual beers will be discussed focusing on taste and flavour stability. These results will be correlated to the analytical data of malt, wort and beer. Correlations between analysed data and the evaluation of flavour stability of beer are shown in Figures 3 and 4.

A high KI and a high amount of soluble nitrogen are known to lead to more Strecker aldehydes in wort [31]. In the presented data this correlation does not apply very well, probably due to the very different kilning procedures and kilning temperatures. But Strecker aldehydes and TBI seem to be a good indicator for flavour stability prognosis. Especially the indicators for thermal load (TBI, Strecker aldehydes, 2-furfural) give important indicators of the quality of malt and wort in respect to flavour stability. Figure 3 shows a significant correlation (P = 0.95) between the sum of Strecker aldehydes in the unboiled wort and the sensory perceived acceptance of the aged beer. The TBI in the unboiled wort even shows a highly significant correlation (P = 0.99) with the acceptance (see Fig. 4). The data underline the comparison of malt, wort and beer analysis are shown in Table 3–5.

During boiling, there is the expected evaporation of aroma substances, like Strecker aldehydes, but the evaporation rates are quite different. The higher the level of Strecker aldehydes in unboiled wort the more substances are evaporated, so that the range of Strecker aldehyde concentration is lowered to a similar level in cast out wort. The prior concentration differences of unboiled wort are no longer visible, but are reflected in the evaluation of beer flavour stability (ageing indicators and sensory evaluation). These results show that the aroma compounds in unboiled wort can be regarded as indicators for the flavour stability of beer (Fig. 3). The formation of aroma compounds, mainly Strecker aldehydes, is due to the malting and mashing procedures, especially to a higher proteolytic modification and a high thermal load during malt and wort production [13]. It must be pointed out, that in this case the correlation between ageing indicators and acceptance of forced aged beer is not significant supposedly as a consequence of the different kilning procedures.

In addition, lipid degradation products are well known to influence flavour stability negatively [12, 25-27, 29-31, 38-40, 56]. Table 6 shows the LOX activity in malt, the lipid degradation product hexanal and the (E)-2-nonenal potential in fresh beer. In these trials no significant correlation between (E)-2-nonenal potential in fresh beer and acceptance of forced aged beer (R = 0.101) is noticeable. Furthermore there is no correlation between LOX activity in malt and hexanal content in unboiled wort. Therefore it is not possible to use LOX activity and formation of lipid degradation products as indicators for the flavour stability of beer. Barley variety, KI and primarily kilning procedures have great influence on LOX activity in malt and the formation of lipid degradation products during malting and mashing [64, 65, 69-74]. In these trials too many impact factors on lipid degradation exist to be able to receive clear correlations. Higher levels of LOX activity and lipid degradation products are critical for flavour stability and can only used as analytical parameters, but other factors have clearly a stronger influence on flavour stability. Fatty acid degradation products under normal conditions do not exceed the flavour threshold [75] in aged beer and therefore they have no influence on the aroma profile of aged beer.

For the correlation of the sensory perceived flavour stability (stale tasting according to Eichhorn) to the analytical data it has to be kept in mind, that flavour stability is influenced by different phenomena (see introduction). For example the antioxidant capacity of the beer influences flavour stability to a considerable extent and it is highly influenced by the strong antioxidant SO_2 which is formed by the yeast during fermentation. This formation is only related to the fermentation condition and the yeast conditions. In these particular trials with two exceptions the SO_2 values were quite low and therefore the resulting beers were comparable. For the two beers with elevated SO_2 values conclusions have to be drawn with caution.

Auriga 1: Auriga 1 received a good DLG rating of the fresh beer (4.32) and as well received a good rating of the aged beer (4.00/1.60, acceptance 75 %). In comparison with Auriga 2 and 3, Auriga 1 shows the best evaluation of the Auriga malts, representing the normal kilning procedure.

The tasting result is confirmed by the low Strecker aldehyde content and the low TBI content in unboiled wort. The ageing components in the fresh beer increased from 30 ppb to 85 ppb in the forced aged beer.

Auriga 2: Auriga 2 received a good evaluation in fresh beer (4.25), but the aged beer (3.94/1.70, acceptance 68.3 %) is less favourable than Auriga 1.

The unboiled wort showed a high content of Strecker aldehydes and the highest TBI (16) of the variety Auriga. The TBI content in beer (35) was the highest of all trials. The ageing components in the fresh beer increased from 41 ppb to 113 ppb in the forced aged beer.

Auriga 3: Auriga 3 received a good evaluation in fresh beer (4.33), but the evaluation of aged beer was also not very good (3.83/1.80, acceptance 65 %).

Remarks to the Auriga trials:

The malt from the Compound Kilning system (kilning system 1) showed higher levels of ageing substances in beer, but these were already present in unboiled wort. There have been more products of Maillard reaction and Strecker degradation, but also more lipid degradation and oxidation products. Less favourable data were found for the trials with a long kilning cycle. It must be pointed out that Auriga 1 and 2/3 come from different germination boxes. Furthermore Auriga 2/3 were kilned at elevated temperatures of 90 °C.

Barke 1: The fresh beer received a good evaluation (4.32), the forced aged beer of Barke 1 was fairly good (4.06/1.55, acceptance 78.3 %).

The level of Strecker aldehydes in unboiled wort was lower than Barke 2, but the TBI was slightly higher (21) than Barke 2 (18). The ageing components in fresh beer increased from 46 ppb to 80 ppb in forced aged beer. The SO_2-content of 4.8 ppm could be partly responsible for the good evaluation of forced aged beer.

Barke 2: Barke 2 was evaluated as one of the best (4.50) fresh beers, but the evaluation of the aged beer (3.88/1.88, acceptance 63.3%) showed poorer flavour stability.

The unboiled wort contained a higher amount of Strecker aldehydes in comparison to Barke 1 and 3. The ageing components in fresh beer increased from 28 ppb to 84 ppb in forced aged beer.

Barke 3: The evaluation of fresh beer of Barke 3 was equal to Barke 2 (4.49) and the aged beer (4.16/1.29, acceptance 90 %) had the best evaluation of all forced aged beers.

The sum of Strecker aldehydes was the lowest of all trials, the same refers to the TBI (9) in malt. The ageing components in the fresh beer increased from 28 ppb to 82 ppb in the forced aged beer. In addition the relatively high SO_2-content (6.8 ppm) supports the flavour stability. The lipid metabolites (e. g. hexanal) and LOX activity were on a low level.

Barke 4: The fresh beer was scored as one of the best beers (4.45) and the aged beer was among the best beers as well (4.15, acceptance 85 %).

The Strecker aldehydes in unboiled wort were on an average level, as well as 2-furfural and lipid metabolites. Ageing compounds increased from 28 ppb to 88 ppb in forced aged beer. TBI was low, which can explain the good rating of forced aged beer.

Remarks to the Barke trials:

The analytical data for the Barke trials differed considerably. For these four trials it is not possible to explain the order of the resulting flavour stability to certain factors as it is possible for most of the other trials. All four malts showed a similar TBI and the sum of Strecker aldehydes in the unboiled wort can not explain the flavour stability since Barke 4 showed an unusual high Strecker aldehyde level but a quite good acceptance level. The SO_2-content and lag-time values as well can only explain partly the results. Barke 3 obtained a very high flavour stability level with the highest amount of SO_2 and quite good results for TBI and Strecker aldehydes but Barke 1 with even a high SO_2-level and a high Lag-time value received a lower acceptance-level compared to Barke 4 with very low levels of SO_2 and Lag-time. This difficulty attributing certain factors to the resulting flavour stability demonstrates that flavour stability is influenced by multiple factors and it is not always possible to predict flavour stability with the existing indicators.

Scarlett: The fresh beer of Scarlett was also evaluated as "good" (4.29); the aged beer (3.88/1.79, acceptance 60.0 %) however was less favourable.

The sum of Strecker aldehydes in unboiled wort was higher than average and also the TBI in malt and beer (14/30) was relatively high. The ageing components in fresh beer increased from 29 ppb to 92 ppb in forced aged beer.

Annabell: The Annabell beer showed the purest and best taste of all fresh beers (4.57), the forced aged beer however was less favourable (3.78/1.88, acceptance 60.0 %).

Unboiled wort of Annabell has the highest content of Strecker aldehydes of all worts in these trials. The level of 2-furfural and TBI in malt and beer were also high. The ageing components in fresh beer increased from 38 ppb to 109 ppb in forced aged beer.

Braemar: The sensory evaluation of fresh Braemar beer presented a slightly greenish, DMS-like (highest DMS-content in malt) taste (4.35), but flavour stability of Braemar was quite good (aged beer: 4.12/1.42, acceptance 83.3 %).

This was confirmed by a very low Strecker aldehyde content in unboiled wort, very low 2-furfural and low TBI. The ageing components in fresh beer increased from 30 ppb to 72 ppb in forced aged beer.

The unequivocally best beers with focus on flavour stability were Barke 3 and Braemar. The latter had also the lowest level of ageing substances. The SO_2/Lag-time situation was markedly better in Barke 3 than Braemar. The varieties Scarlett and Annabell had poor flavour stability in these trials.

4 Conclusion

1. The protein content of the malts was in the range of 10.1-10.9 %; the amount of soluble nitrogen (669-735 mg/100g dm), especially the "nitrogen-load" was further determined by the KI, which varied between 38.6 and 44.5 %. In general a low KI and a low level of soluble nitrogen is favourable for flavour stability. [31] It could be demonstrated, that the content of Strecker aldehydes in unboiled wort gives a good hint on flavour stability of beer. For these trials can be stated, that differences in kilning procedure and especially the absolute kilning temperature should be noted for evaluation of different malts and unboiled worts with regard to flavour stability of beer. In addition for the correlation of sensory perceived flavour stability (stale tasting according to Eichhorn) to the analytical data it had to be kept in mind, that flavour stability is influenced by different phenomena (see introduction). Therefore a change in one technological parameter may well amend one of the influence factors but may simultaneously change any of the others unwillingly.
2. The TBI of malt correlates with CWC and BWC. A low TBI value is a basis for better flavour stability. This is also reflected in the evaluation of fresh and aged beers. The higher the thermal load of malt, the higher the TBI.
3. The trials show no significant correlation between LOX activity in malt, hexanal content in unboiled wort, (E)-2-nonenal potential in fresh beer and acceptance of forced aged beer. For this reason the lipid metabolites give no hint on flavour stability of beer for the present samples. Furthermore a lot of other impact factors on lipid degradation have to be considered like KI, barley variety (LOX activity) and kilning procedure. Higher levels of LOX activity and lipid degradation products were found in literature to influence flavour stability in some ways, but they can only be used as analytical parameters. The suppression of LOX activity for Barke 3 and 4 during the malting procedure can be confirmed by the analysis of

LOX activity. Other factors have clearly stronger influence on flavour stability like Strecker aldehydes.

4. The trials of Compound Kilning System (long and short drying/kilning cycle) resulted in similar malt specifications (Auriga 2 and 3). There were no obvious differences in malt analysis data caused by the effect of longer drying/kilning cycle. Although the evaluation of fresh and aged beer was similar, both beers showed unfavourable flavour stability, due to higher kilning temperatures.
5. Defective malts (Annabell, to some extent also Scarlett) either by over modification during germination or mistakes during the drying/kilning process lead to beers of poorer flavour stability. The higher TBI of these malts was a good indicator for this phenomenon.
6. *Prima facie*, the aroma components of unboiled wort in the Barke trials did not correspond well with the ageing substances of fresh and forced aged beers (especially by Barke 1). This can be ascribed to great differences in the SO_2 content respectively the Lag-time analysis. In general the highest wort aroma contents led also to high amounts of ageing compounds, like it is documented in the results of Annabell, Scarlett, Auriga 2 and Auriga 3.
7. It had to be considered that the SO_2-content of most beers was very low, so that only fairly small differences in the SO_2-levels were existent. Thus in these trials (except of Barke 1 and 3) the SO_2-levels might not superimpose the influence of other factors.
8. The malt of Barke 3 showed very favourable results: low TBI and low DMS-P as well as low hexanal (indicator of LOX activity) values in unboiled and boiled wort. In addition fresh beer showed the highest SO_2 content (influenced only by fermentation) and best Lag-time. This beer had best flavour stability, confirmed by the lowest amount of Strecker aldehydes in wort, but also the lowest KI. So Barke 3 fulfils the specifications for the production of a very flavour stable beer.

By purchasing malt and also by selection of malting technology we have to keep attention on some important parameters, which support good flavour stability. This parameters and indicators could be traced by different analyses from malt over wort to fresh and forced aged beer.

A low amount of Strecker aldehydes in malt, wort and fresh beer, high SO_2 contents and thus long Lag-times lead to better flavour stability. The TBI of malt and fresh beer could be a useful indicator for the favourable properties influencing flavour stability. In addition the amount of volatile aroma compounds in unboiled wort act as good indicators for evaluation of flavour stability. This is demonstrated by the positive flavour stability of Barke 3 (in addition affected by the high SO_2 content) and Braemar; the opposite is demonstrated in the trials with Annabell and Scarlett.

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Appendix

Table 1 **Malts and their malting procedure**

malt	malting procedure
Auriga 1	single floor kiln, 20 hours cycle time, kiln-off temp. 83 °C
Auriga 2	long kilning cycle, higher load, 36 hours cycle time, kiln-off temp. 90 °C, out-air after breakthrough
Auriga 3	short kilning cycle, lower load, 20 hours cycle time, kiln-off temp. 90 °C, out-air after breakthrough
Barke 1	single floor malt, 20 hours cycle time, kiln-off temp. 85 °C
Barke 2	long kilning cycle, higher load, 36 hours cycle time, kiln-off temp. 85 °C
Barke 3	use of return-air to enrich CO_2 during germination, kilning like Barke 2
Barke 4	floor malt, single floor kiln, kiln-off temp. 83 °C
Annabell	single floor kiln, 20 hours cycle time, kiln-off temp. 83 °C
Braemar	pilot malting, 200 kg set, kiln-off temp. 78 °C
Scarlett	commercial malt

Table 2 **Malt analyses**

analysis			Barke 1	Barke 2	Barke 3	Barke 4
moisture	MEBAK I 4.1.4.1	%	4.0	3.5	4.1	5.8
extract	MEBAK I 4.1.4.2.2	%, as is	79.2	79.3	78.9	77.4
extract	MEBAK I 4.1.4.2.2	%, dm	82.5	82.2	82.3	82.2
viscosity (8,6 °P)	MEBAK I 4.1.4.4.1	mPa s	1.490	1.510	1.528	1.496
visocisity 65 °C (8,6 °P)		mPa s	1.527	1.545	1.596	1.537
friability	MEBAK I 4.1.3.6.1	%	92.7	90.8	86.8	90
friability over 2.2 mm	MEBAK I 4.1.3.6.1	%	0.8	0.9	1.1	0.1
saccharification time	MEBAK I 4.1.4.2.4	min.	< 10	< 10	< 10	< 10
final attenuation	MEBAK I 4.1.4.10	%, app.	82.1	82.2	83	82
colour of wort	MEBAK I 4.1.4.2.8.2	EBC	3.3	3.4	3.3	3.2
boiled colour	MEBAK I 4.1.4.2.8.2	EBC	5.6	5.7	5.4	5.1
pH	MEBAK I 4.1.4.2.7		5.83	5.93	5.91	5.96
crude protein	MEBAK I 4.1.4.5.1.1	%, dm	10.1	10.4	10.9	9.8
soluble nitrogen	MEBAK I 4.1.4.5.2	mg/100g dm	719	669	674	593
Kolbach Index	MEBAK I 4.1.4.5.3	%	44.5	40.2	38.6	37.8
FAN	MEBAK I 4.1.4.5.5	mg/100g dm	145	137	133	115
Hartong 45 °C	MEBAK I 4.1.4.11	%	42.3	37.6	38.2	36.3
β-glucan content 65 °C	MEBAK I 4.1.4.9.2	ppm	167	203	276	188
homogeinity	MEBAK I 4.1.3.8	%	88	88	83	87
modification		%	98	98	96	98
DMS precursor		ppm, as is	5.3	4,4	2.2	3.8
grading > 2.8 mm	MEBAK I 2.3.1	%	87.9	88.4	85.2	92.6
grading 2.5 – 2.8 mm	MEBAK I 2.3.1	%	9.6	9.6	12.2	6.1
grading 2.2 – 2.5 mm Malz	MEBAK I 2.3.1	%	1.8	1,3	2.1	0.9
residue	MEBAK I 2.3.1	%	0.7	0.7	0.5	0.4
crude lipid		%	1.6	1.6	1.2	1.6
TBI (Birkenstock)			10	10	9	9

Table 2 (cont.) Malt analyses

analysis			Auriga 1	Auriga 2	Auriga 3	Scarlett	Annabell	Braemar
moisture	MEBAK I 4.1.4.1	%	4.2	4.3	3.9	3.8	3.1	5.1
extract	MEBAK I 4.1.4.2.2	%, as is	76.9	77.0	77.5	79.5	78.3	77.8
extract	MEBAK I 4.1.4.2.2	%, dm	80.3	80.5	80.6	82.6	80.8	82.0
viscosity (8.6 °P)	MEBAK I 4.1.4.4.1	mPa s	1.523	1.541	1.549	1.555	1.517	1.483
visocisity 65 °C (8.6 °P)	mPa s	1,565	1.562	1.605	1.626	1.535	1.523	
friability	MEBAK I 4.1.3.6.1	%	92.3	87.9	91.3	82.2	96.4	91.3
friability over 2.2 mm	MEBAK I 4.1.3.6.1	%	0.5	1.6	0.8	0.9	0.4	0.5
saccharification time	MEBAK I 4.1.4.2.4	min.	< 10	< 10	< 10	< 10	< 10	< 10
final attenuation	MEBAK I 4.1.4.10	%, app.	82.5	81.8	81.9	82.8	80.9	82.9
colour of wort	MEBAK I 4.1.4.2.8.2	EBC	3.5	3.9	3.5	3.5	4.2	3.5
boiled colour	MEBAK I 4.1.4.2.8.2	EBC	5.5	6.2	6.0	5.7	6.9	5.8
pH	MEBAK I 4.1.4.2.7		5.94	5.88	5.89	5.90	5.91	6.01
crude protein	MEBAK I 4.1.4.5.1.1	%, dm	10.5	10.5	10.4	10.7	10.8	10.6
soluble nitrogen	MEBAK I 4.1.4.5.2	mg/100g dm	719	715	713	685	735	709
Kolbach Index	MEBAK I 4.1.4.5.3	%	42.8	42.6	42.8	40.0	42.5	41.8
FAN	MEBAK I 4.1.4.5.5	mg/100g dm	154	144	149	138	149	146
Hartong 45 °C	MEBAK I 4.1.4.11	%	38.8	37.7	36.5	39.9	34.7	38.1
β-glucan content 65 °C	MEBAK I 4.1.4.9.2	ppm	123	104	177	157	104	143
homogeinity	MEBAK I 4.1.3.8	%	92	92	86	77	88	91
modification	%	99	99	98	95	98	99	
DMS precursor	ppm, as is	6,1	4.4	4.4	3.2	4.0	9.3	
grading > 2.8 mm	MEBAK I 2.3.1	%	84.8	86.3	86.3	89.2	83.6	88.9
grading 2.5 – 2.8 mm	MEBAK I 2.3.1	%	12.5	11.3	11.2	8.8	13.5	8.9
grading 2.2 – 2.5 mm Malz	MEBAK I 2.3.1	%	1.9	2.0	2.3	1.4	2.0	1.4
residue	MEBAK I 2.3.1	%	0.8	0.4	0.2	0.6	0.9	0.8
crude lipid	%	1,5	1.5	1.5	1.6	1.6	1.6	
TBI (Birkenstock)		11	16	13	14	15	9	

Table 3 Analytical data of Auriga

		Auriga 1	Auriga 2	Auriga 3
ranking flavour stability		**1**	**2**	**3**
DLG fresh		4.32	4.25	4.33
DLG forced		4.00	3.94	3.83
acceptance forced aged beer	%	75.0	68.3	65.0
Kolbach index, malt	%	42.8	42.6	42.8
soluble nitrogen, malt	mg/100 g dm	719	715	713
TBI, malt		11	16	13
TBI, unboiled wort		21	26	24
TBI, beer		27	35	29
strecker aldehydes, unboiled wort	ppb	405	992	1047
strecker aldehyde, cast out wort	ppb	264	270	279
2-furfural, unboiled wort	ppb	40	98	88
2-furfural, cast out wort	ppb	124	174	130
SO_2, beer	ppm	1.0	0.2	1.3
Lag-Time, beer	min.	47	32	54

Table 4 Analytical data of Barke

		Barke 3	Barke 4	Barke 1	Barke 2
ranking flavour stability		**1**	**2**	**3**	**4**
DLG fresh		4.49	4.45	4.32	4.50
DLG forced		4.16	4.15	4.06	3.88
acceptance forced aged beer	%	90.0	85.0	78.3	63.3
Kolbach index,malt	%	38.6	37.8	44.5	40.2
soluble nitrogen, malt	mg/100 g dm	674	593	719	669
TBI, malt		9	9	10	10
TBI, unboiled wort		14	18	21	18
TBI, beer		22	21	24	23
strecker aldehydes, unboiled wort	ppb	661	807	695	816
strecker aldehyde, cast out wort	ppb	137	186	215	225
2-furfural, unboiled wort	ppb	59	76	58	54
2-furfural, cast out wort	ppb	73	100	97	104
SO_2, beer	ppm	6.8	0.3	4.8	0.2
Lag time, beer	min.	132	39	64	25

Table 5 Comparison of the different malts

		Braemar	Barke 1	Auriga 1	Scarlett	Annabell
ranking flavour stability		**1**	**2**	**3**	**4**	**5**
DLG fresh		4.35	4.32	4.32	4.29	4.57
DLG forced		4.12	4.06	4.00	3.88	3.78
acceptance forced aged beer	%	83.3	78.3	75.0	60.0	60.0
Kolbach index, malt	%	41.8	44.5	42.8	40.0	42.5
soluble nitrogen, malt	mg/100 g dm	709	719	719	685	735
TBI, malt		9	10	11	14	15
TBI, unboiled wort		15	21	21	24	26
TBI, beer		21	24	27	30	31
Strecker aldehydes, unboiled wort	ppb	534	695	405	939	1268
Strecker aldehyde, cast out wort	ppb	314	215	264	336	241
2-furfural, unboiled wort	ppb	37	40	40	87	93
2-furfural, cast out wort	ppb	94	124	124	157	121
SO_2, beer	ppm	1.8	4.8	1.0	1.9	0.4
Lag-Time, beer	min.	60	64	47	52	45

Table 6 **LOX activity in malt, lipid degradation products (hexanal, (E)-2-nonenal potential in fresh beer)**

	LOX activity in malt [U/ml]	(E)-2-nonenal potential [ppb]	hexanal, unboiled wort [ppb]	hexanal, cast out wort [ppb]	acceptance, forced aged beer [%]
Braemar	56.22	0.212	70	14	83.3
Scarlett	27.34	0.086	81	12	60.0
Annabell	19.54	0.227	98	3.9	60.0
Auriga 1	36.34	0.236	43	4.6	75.0
Auriga 2	30.96	0.246	88	4.6	68.3
Auriga 3	37.11	0.182	82	4.6	65.0
Barke 1	57.54	0.095	146	6.6	78.3
Barke 2	33.71	0.087	72	5.7	63.3
Barke 3	17.57	n. d.	76	2.6	90.0
Barke 4	24.16	0.144	97	4.1	85.0

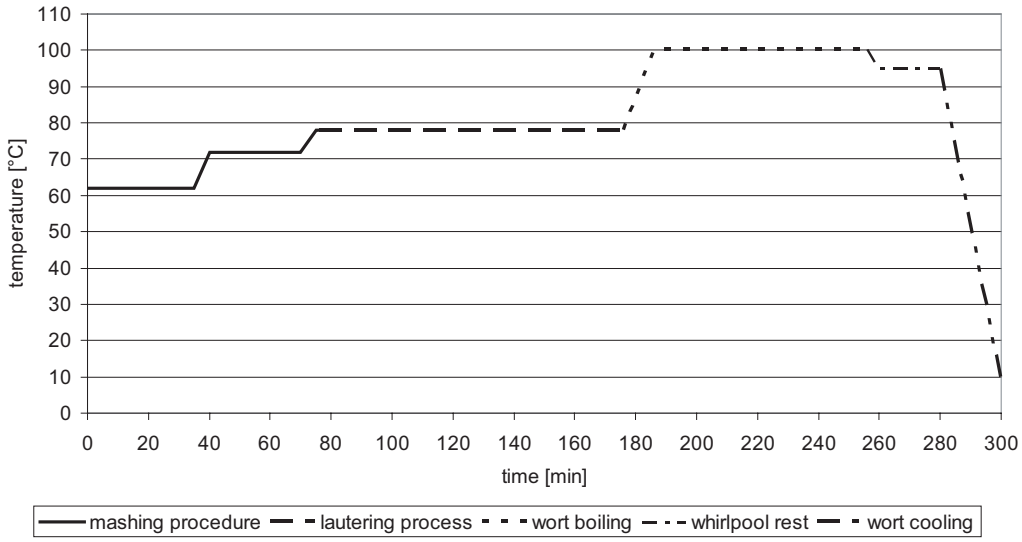

Fig. 1 **Procedure of wort production**

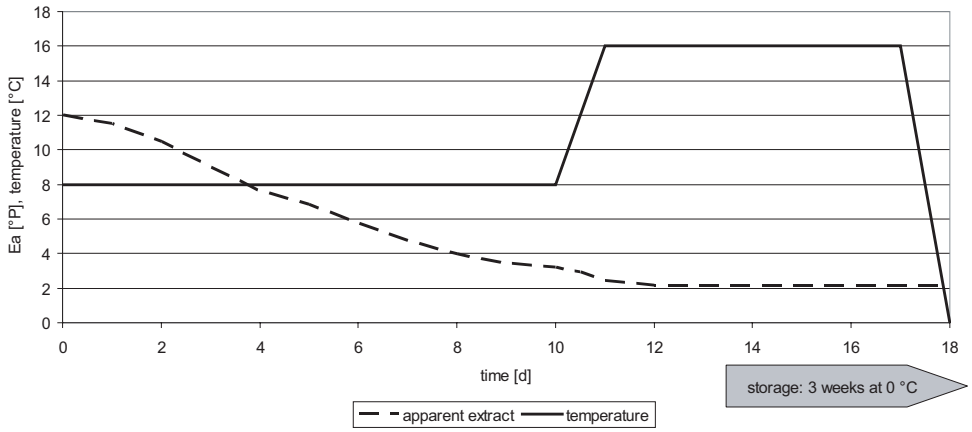

Fig. 2 Fermentation and storage process

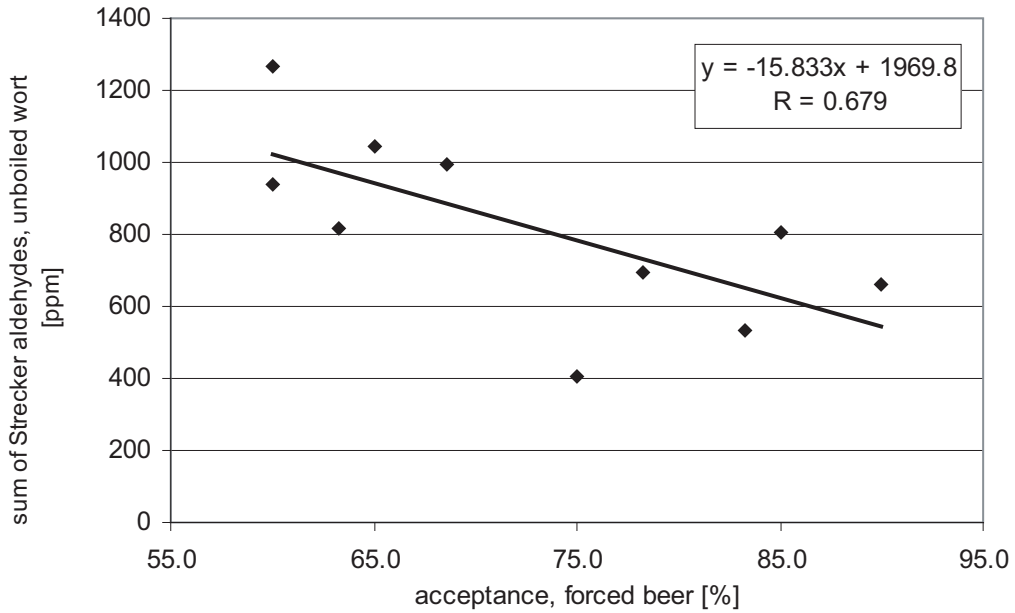

Fig. 3 Acceptance vs. sum of Strecker aldehydes in unboiled wort

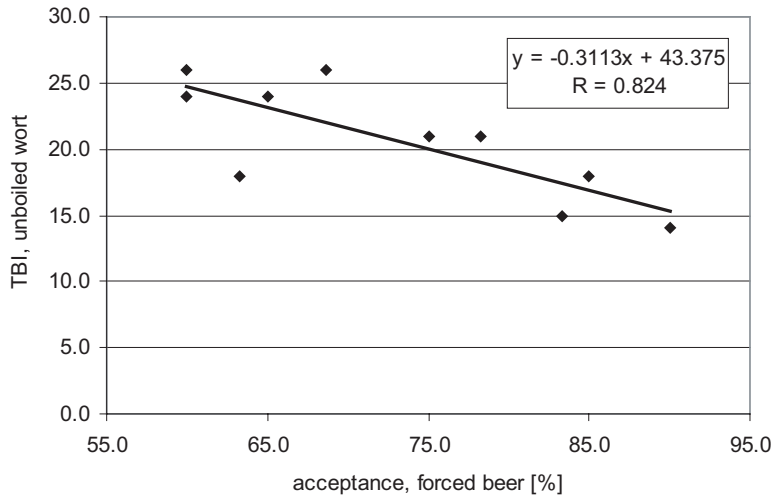

Fig. 4 Acceptance vs. TBI in unboiled wort